Cost Reduction Potential of the DSN Data Base

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TDA Planning

The cost of the DSN data base can be reduced by computerizing and unifying the current multiplicity of separate manual, computer, and hybrid data bases. Savings would accrue from eliminating all manual system costs, increasing efficiency in data base implementation and maintenance-and-operation, and increasing data accuracy. By applying a simple mathematical savings model to current data base costs, this study estimates the probable range of net ten-year savings. The minimum net savings, under the assumptions of the study, is calculated as $7.5 million.

I. Introduction

The evolving technology and methodology in data bases have now reached the point at which the DSN can properly consider unifying its approach to specification and control of the operational DSN data base. The DSN is currently using computers in most of the separate data bases. Now the technology exists for a unified DSN data base that optimally splits functions between hardware, software, and people to maximize service to the end user within life-cycle cost constraints. These productivity improvements can arise from a reduction in both paperwork and data errors, not to mention the provision of much more timely access to the data required for Operations, Operations Support, and DSN Management. It is the purpose of this article to conservatively estimate the cost saving potential of this unified approach to the DSN data base.

The evolving Configuration Control and Audit (CCA) Assembly proposes to combine all the DSN distended data bases under one structured, though decentralized, computer system. Designed to minimize redundant data, reduce operating costs, and increase productivity (Ref. 1), the CCA Assembly would have a structured data base and user terminals at each DSN complex (Goldstone, Australia, and Spain). A JPL master data base would be in weekly communication with each through existing GCF high-speed, two-way transmission links. The data base structure is planned as a standardized, cross-referenced, hierarchical tree of files such that all users input data according to a standard format at an on-line terminal (Ref. 2). Integrity of the input is the responsibility of the respective complex.

The question addressed by this study is then: given the present data base structure and work load, what would be the life cycle savings (or disavings) accompanying conversion to such a structured computerized data base? The savings model, called DBSAVE and expanded in Appendix B, addresses this problem and estimates the net ten-year savings likely to result from the DSN data base structuring and unification.

II. Data Base Savings Model — DBSAVE

The present DSN data base structure can be characterized as follows:

(1) Manual data base systems.

(2) Computerized data base systems, composed of:

(a) Pure computer time.

(b) Manual input to computer.

The present total DSN data base yearly costs (CT1) can also be divided into the categories shown in Table 1.

Hypothetically, the conversion of this structure to one unified computerized system can be viewed as a two-step process. First, all manual systems (any manual gathering, storing, filing, and updating of data) are converted to computer. There is an efficiency ratio (call it EFF1) of time as employed in the old manual data base system to time as used in the new computerized system. When applied to the present manual data base system costs, EFF1 will give rise to the savings (or disavings) of step 1. Call these savings SAV1. At this point, all data is now on computer, but the various computerized data base systems are nonrelated.

Next, all the now computerized data systems are unified under one structured system. Again, there is an efficiency ratio between the old computer systems and the structured computer system. This ratio may well differ for the two computer data base system components – computer time and manual input. So these are treated separately with:

EFF2: the efficiency ratio of computer time as used in a nonstructured computer system to that as used in the unified computer system.

EFF3: the efficiency ratio of manual input time as used in a nonstructured computer system to that as used in the unified computer system.

Applying these efficiency ratios to the proper computer component costs (including the extra loads derived from step 1) results in the step 2 savings (or disavings) SAV2 and SAV3.

Thus, the data flow for model DBSAVE can be visualized as shown in Fig. 1.

This two-step model of the data base conversion process is not altogether hypothetical. Many older manual data bases were converted to separate computer systems, and now will be unified under the CCA Assembly. The model fits the current structure of the DSN data base, the final system toward which the CCA is aimed, and is not an unreasonable description of the intermediate process.

In addition to savings SAV1, SAV2, and SAV3, are the yearly savings, called ERSAVE, derived from the increased accuracy of the DSN data base. The total gross yearly savings (SAVTOT) from the two-step process are then simply:

$$\mathrm{SAVTOT} = \mathrm{SAV1} + \mathrm{SAV2} + \mathrm{SAV3} + \mathrm{ERSAVE}$$

The net ten-year savings (NETSAV) are:

$$\mathrm{NETSAV} = (\mathrm{SAVTOT}*10) - (\text{ten-year costs of data base conversion})$$

Each component of the SAVTOT and NETSAV calculations is further explained in the following sections.

A. Section SAV1

SAV1 is derived from the elimination of all manual data base costs, by converting manual systems to computer. Obviously, the savings will be the difference between the original manual data base costs and the new computer costs from this added work load. The new computer costs will depend on the relative efficiency of the manual to computer systems, EFF1.

The value for EFF1 is not precisely known, so EFF1 is parameterized in DBSAVE as a 1×4 vector with four possible values. There is no restriction, within the model, on the maximum or minimum value of the EFF1 elements. These are delegated to the choice of the user. Letting A be a 1×4 vector with each element equal to 1, the first savings are:

$$\mathrm{SAV1} = \mathrm{CM1} - (\mathrm{EFF1}*\mathrm{CM1}) = (\mathrm{A} - \mathrm{EFF1}) * \mathrm{CM1}$$

Four possible SAV1 values, either positive or negative, are thus calculated.

B. Section LOAD

Step 2 converts all computer systems, including those derived in step 1, to the unified computer data base. First it is necessary, however, to calculate the extra computer system costs derived from the earlier manual to computer data base conversion. This extra cost, called CTC2, is calculated:

$$\mathrm{CTC2} = \mathrm{EFF1} * \mathrm{CM1}$$

As CTC2 depends on EFF1, it is also a 1×4 vector.

C. Section SAV2

Some portion of this load, CTC2, is pure computer time. This portion is likely to vary for different data bases. A good average value is the ratio of present computer time costs to total computer data base costs, or CCC1/CTC1. Though the computer time and manual input portions may not be exactly averageable over work units, any discrepancy from the chosen average can be absorbed in the variables EFF2 and EFF3.

Thus, the extra computer time costs, CCC2, from the manual system to computer conversion, are:

$$CCC2 = (CCC1/CTC1) * CTC2 \qquad (1 \times 4 \text{ vector})$$

Now the total computer time costs, CCC3, to be converted to the unified computer system, must be the sum of the manual-converted costs plus present costs, or:

$$CCC3 = (CCC1 * A) + CCC2 \qquad (1 \times 4 \text{ vector})$$

(The A vector is necessary to conform the scalar CCC1).

The total computer time can now be converted to the unified system. EFF2, the nonsystematic-to-systematic computer time ratio, is parameterized as a 4 X 1 vector. (The vector directions are chosen so that in the final NETSAV 4 X 4 X 4 matrix, each EFF parameter will vary in a different direction). Again, there are no size restrictions within the model placed on the EFF2 values.

Thus, the savings (positive or negative) from the conversion of computer time to the structured computer system are:

$$\begin{aligned} SAV2 &= CCC3 - (EFF2 * CCC3) \\ &= (B - EFF2) * CCC3 \qquad (4 \times 4 \text{ vector}) \end{aligned}$$

where B is a 4 X 1 vector with all elements equal to 1.

D. Section SAV3

This section is symmetric to Section SAV2. The same equations are used, with manual input to computer substituted for computer time. Thus the extra manual input to computer costs, from step 1, is:

$$CMC2 = (CMC1/CTC1) * CTC2$$

The total manual input to computer costs is:

$$CMC3 = (CMC1 * B) + CMC2$$

Therefore the savings (positive or negative) from the conversion of manual input to the structured computer system are:

$$SAV3 = (B - EFF3) * CMC3 \qquad (4 \times 4 \text{ vector})$$

E. Section SAVTOT

As earlier stated:

$$SAVTOT = SAV1 + SAV2 + SAV3 + ERSAVE$$

For conformity, the SAV matrices are extended to three dimensions (I, J, K) so that the three efficiency ratio parameters vary along different axes. Specifically, EFF1 of SAV1 varies along the K axis, EFF2 of SAV2 varies along J, and EFF3 of SAV3 varies along I. ERSAVE must be a 4 X 4 X 4 matrix with each element equal to the ERSAVE value.

F. Section NETSAV

This final section calculates the estimated ten-year net savings of the unified computerized data base system. First, the values of the two quantifiable system costs – IMPL and MO – are prompted from the program user. IMPL is the estimated implementation cost of the unified system. MO is the estimated yearly maintenance and operations cost for the system.

The ten-year estimated cost, then, is:

$$COST = IMPL + (MO * 10)$$

To conform to the SAVTOT matrix, COSTS is the proper 4 X 4 X 4 matrix, with each element equal to COST. Then,

$$NETSAV = (SAVTOT * 10) - COSTS$$

III. Values of Constants and Variables

A. Value of Constants

The values of the constants for the model were determined through interviews with the cognizant individuals of forty WAD 76-1 work units likely to include major data base functions. These were both in-house and M&O units. Of these, twenty-one did have noticeable data base costs. The results of the interviews are shown in Table 2. The values for the constants in DBSAVE are given in Table 3. The values in Table 3, it should be noted, are "ballpark" figures. The information solicited in the interviews was often not obvious from the Work Authorization Document. So, though the data represent information gained from knowledgable personnel, they are necessarily somewhat "gut-level" in nature.

There are other effects, however, which would tend to offset inaccuracies. First, it is reasonable to assume that any errors are randomly distributed, thus having a self-canceling effect. Also, very importantly, all the relevant work units were undoubtedly not found during the survey. This would down-bias the final savings figures, if anything.

B. Value of ERSAVE

The yearly savings due to the increased accuracy of the DSN data base, ERSAVE, are assigned the value of \$877k/yr. Based on industry-accepted error rates and current cost of the data base, the estimated present cost of DSN data base errors is \$975k/yr (in 1976 dollars) (Ref. 3). Under the final system this figure will be reduced by a factor of ten (Ref. 4). Thus:

$$\text{ERSAVE} = (\$975/\text{k}) * (0.9) = \$877\text{k/yr}$$

C. Values of Variables

The values for the efficiency ratio vectors were chosen as:

$$\text{EFF1} = (0.5, 0.75, 0.825, 0.95)$$

$$\text{EFF2} = (0.1, 0.55, 0.605, 1.0)$$

$$\text{EFF3} = (0.3, 0.65, 0.715, 1.0)$$

In justification of these values, they are first of all *averages* over all data bases. For instance, though EFF1 is possibly greater than one for a very small data base, over all data base work the average will be less than one. In substantiation of this assertion are the results of the first phase of the Goldstone Facility Maintenance computerized data base system. F. R. Maiocco and J. P. Hume report "the following improvements in the Work Control Center's efficiency have been achieved:"

(1) "Report preparation time, which took from 2 to 4 weeks [under the manual system], has been significantly reduced to basically computer access time."

(2) "Computation errors are basically non-existant and the accuracy of the reports is dependent upon the accuracy of the data input to data files."

(3) "Expanded capability exists in energy reporting not previously available in the manual recording system (Ref. 7)."

Thus, the likely range of EFF1 is conservatively selected as 0.5 to 0.95. The second EFF1 element, 0.75, is simply the midrange value. The third element of each efficiency vector is 10% greater than the second element, for use later in sensitivity tests. For EFF1, this test value is 0.825.

The values chosen for EFF2 and EFF3 are not otherwise substantiated. The assumption is simply made that computer time and manual input time will not be less efficient under the structured, computer data base system, than under an unstructured system. It is believed that this is the case; however, there exists no data in the literature to test the assumption. Evaluation of the first phase of the CCA Assembly will hopefully provide solid evidence, one way or the other. Until then, the results of this study must be viewed with this assumption in mind.

Thus, the range of EEF2 was chosen as 0.1 to 1.0, and EFF3 as 0.3 to 1.0. Again the second elements are midrange values, and third elements are test values.

D. Values of Structured Data Base System Costs

The CCA Assembly system costs are estimated in Table 4, which are the costs for the CCA Assembly only. All other data base costs are encompassed in the model's cost efficiency calculations.

IV. Computer Output of the Model

A. Savings Estimates

This output is shown in Fig. 2.

Note that in reading the computer output of a three-dimensional matrix (I, J, K), the K axis varies most rapidly, then the J, and lastly the I. For example, the corresponding three-dimensional elements for the first six rows of matrix output are:

(1, 1, 1)	(1, 1, 2)	(1, 1, 3)	(1, 1, 4)
(1, 2, 1)	(1, 2, 2)	(1, 2, 3)	(1, 2, 4)
(1, 3, 1)	(1, 3, 2)	(1, 3, 3)	(1, 3, 4)
(1, 4, 1)	(1, 4, 2)	(1, 4, 3)	(1, 4, 4)
(2, 1, 1)	(2, 1, 2)	(2, 1, 3)	(2, 1, 4)
(2, 2, 1)	(2, 2, 2)	(2, 2, 3)	(2, 2, 4)

B. Output Evaluation

1. Sensitivity. Before even examining the estimated net savings, the sensitivity of the model must be checked. The computer program for the savings model provides tests of the sensitivity of the savings estimates with respect to changes in variables and constants. The method used is fully explained in Appendix C and results are given in Appendix D.

The sensitivity test results are very encouraging. If the EFF1 value is increased 10% from midrange, the estimated net savings decreases by only 4%. For a 10% increase in the variable EFF2, NETSAV decreases only 2%, and likewise only 4% for EFF3. Even when all three are increased by 10%, NETSAV decreases by 11%. There are, therefore, no "blow up" points in the results with respect to the variables.

The NETSAV sensitivity with respect to constants is also quite acceptable. At the most, NETSAV increases by 5% when the CM1 constant is increased by 10%.

Thus, the net savings calculations are not highly sensitive to changes in variables, or errors in constants.

2. Nonquantifiable costs and savings. The ten-year costs of the proposed system are seen as $1,967k. There are other costs, however, which could not be quantified. For example, some personnel involved in the data base work may need additional training. There is some cost of data inaccessability when one of the computers is temporarily down. Finally, there may be a temporary cost of maintaining constant output during the period of transition to the unified system.

Hopefully, the nebulous costs are minor and/or are offset by corresponding qualitative savings. For instance, the external savings from the increased system accuracy could not be quantified. Also, substantial expected savings from decreased turnaround time were omitted. Finally, the potential use of the increased data capacity of the system could not be included in the model.

3. Quantitative savings. In any case, the quantitative savings results are clear. In general, NETSAV varies linearly with each variable, yet nonlinearly with respect to all three variables. It varies such that at the lower savings range, greater then linear increases in NETSAV result from linear decreases in variables. (See the graphs in Appendix A.) This means that at the minimum range of possible net savings, the region most important in a policy decision, greater than linear gains in NETSAV result from a slight decrease in estimated EFF values. This result, too, is encouraging.

This nonlinearity points out that the previous sensitivity results are limited to the assumptions under which they were made. In other words, since the tests dealt with the midrange of the NETSAV curve, it is here that the results apply. Until a more exact study is required – one dealing in specific values rather than variables – the tests performed here are sufficient.

Finally, in magnitude, the net ten-year estimated savings range from $7,584.8k to $24,620.2k. Therefore, even in the least savings case, where the manual system to computer system efficiency ratio equals 0.95 and the other efficiency ratios are unity, the estimated net ten-year savings are still $7.5 million. At the other extreme is an estimated $24 million savings.

Thus, if the assumptions made in this study are valid, substantial savings are clearly possible – the DSN data base does indeed have a strong potential for cost reduction.

References

1. A. I. Bryan, private communication.
2. For more information on the current status of the Configuration Control and Audit Assembly, see A. I. Bryan, "A Distributed Data Base Management Capability for the Deep Space Network," *JPL Deep Space Network Progress Report 42-33,* Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1976.
3. E. C. Posner, private communication.
4. E. C. Posner, private communication.
5. F. R. Maiocco and J. P. Hume, "Computerizing Goldstone Facility Maintenance Data for Management Decisions," *JPL Deep Space Network Progress Report 42-32,* p. 313, Jet Propulsion Laboratory, Pasadena, Calif., April 15, 1976.
6. E. C. Posner, private communication. This estimates the one-time cost, with reference to the CCA Assembly, in converting manual data bases to computer.
7. E. C. Posner, private communication.

Table 1. DSN data base yearly cost categories

Category	Name of constant in model
Cost of total manual data base, including overhead	CM1
Cost of total computer data base	CTC1
Cost of computer time of computer data base	CCC1
Cost of manual input to computer data base	CMC1

Table 2. Value of constants

JPL work unit No.	Computer time cost per year, $k	Manual input cost per year, $k	Total computer cost per year, $k	Total manual data base cost per year, $k
12-10-02	45.0	0.0	45.0	0.0
12-30-01	3.0	0.0	3.0	96.3
12-30-03	0.0	0.0	0.0	2.6
13-31-01	62.0	6.5	68.5	0.0
13-31-04	0.0	0.0	0.0	193.0
13-41-04	0.0	0.0	0.0	2.4
13-41-06	0.0	0.0	0.0	3.0
13-41-07	0.0	0.0	0.0	4.6
31-10-55	9.3	26.0	35.3	0.0
31-20-90	8.0	14.0	22.0	0.0
43-20-04	2.2	0.0	2.2	34.2
43-20-09	18.0	44.0	62.0	0.0
44-10-01	3.0	0.0	3.0	7.0
44-10-02[a]	0.5	4.0	4.5	4.5
44-30-01	27.0	195.0	222.0	0.0
Subtotal 1:	178.0	289.5	467.5	347.6
Goldstone work units: No.				
11-10-01	2.0	11.6	13.6	68.0
11-10-02	0.0	0.0	0.0	93.0
11-11-02	0.0	0.0	0.0	59.2
11-11-04	0.0	0.0	0.0	50.1
11-12-05[b]	0.0	0.0	0.0	120.0
11-12-10	0.0	2.0	2.0	55.0
Subtotal 2:	2.0	13.6	15.6	445.3
Overseas station costs estimated as twice the applicable Goldstone costs				
Subtotal 3:	4.0	27.2	31.2	770.6
Total	184k/yr	330.3k/yr	514.3k/yr	1563.5k/yr

[a]This is a new unit. The cost values are estimated as half the unit's budget, split evenly between manual data base costs and computer data base costs.

[b]Only half of this unit's costs are applicable to overseas stations.

Table 3. Constants in DBSAVE

Meaning of the constant	Value, $k	Constant name
Cost of total DSN data base	2077.8	CT1
Cost of total computer data base	514.3	CTC1
Cost of computer time of computer data base	184.0	CCC1
Cost of manual input to computer data base	330.3	CMC1
Cost of total manual data base (including overhead)	1563.5	CM1

Table 4. CCA Assembly system costs

Cost explanation	Value	Model name
Implementation costs (from WAD 76-2)		IMPL
Station configuration control audit engineering	$488k	
Station configuration control audit equipment	$879k	
CCA Assembly costs distributed in operations accounts (Ref. 6)	$100k	
Total	$1467k	
Maintenance and operations costs (Ref. 7)	$50k/yr	MO
0.5 manyear (JPL)		
1.0 manyear (contractor)		
$5k for parts		

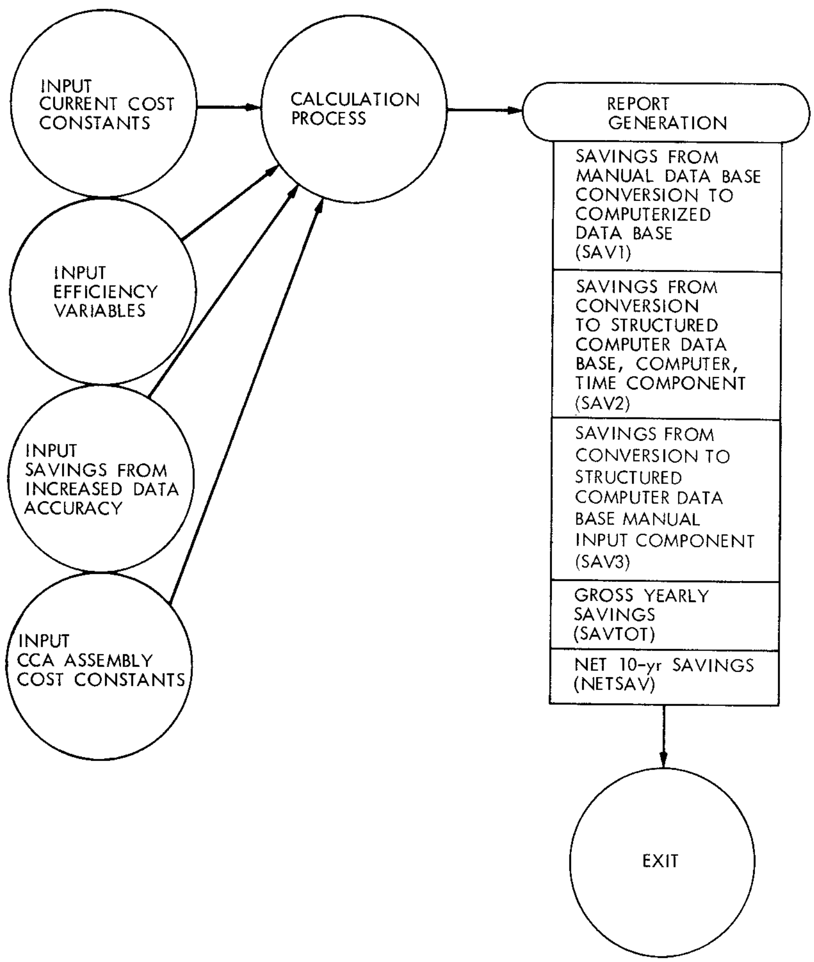

Fig. 1. Data flow for model DBSAVE

```
>RUN
CT1: 2077.0
CTC1: 514.3
CCC1: 184.0
CMC1: 330.3
CM1: 1563.5
ERSAVE: 877
ENTER EFF1: .5
ENTER EFF1: .75
ENTER EFF1: .825
ENTER EFF1: .95
ENTER EFF2: .1
ENTER EFF2: .55
ENTER EFF2: .605
ENTER EFF2: 1.0
ENTER EFF3: .3
ENTER EFF3: .65
ENTER EFF3: .715
ENTER EFF3: 1.0

SAVINGS CALCULATIONS


SAV1 IN $K:     791.7     390.9     273.6      79.2


SAV2 IN $K:
     417.3     543.2     580.9     643.9
     208.7     271.6     290.5     321.9
     183.2     238.4     255.0     282.6
       0.0       0.0       0.0       0.0


SAV3 IN $K:
     582.7     758.4     811.1     899.0
     291.3     379.2     405.5     449.5
     237.2     308.8     330.2     366.0
       0.0       0.0       0.0       0.0


SAV3 IN $K:
     582.7     758.4     811.1     899.0
     582.7     758.4     811.1     899.0
     582.7     758.4     811.1     899.0
     582.7     758.4     811.1     899.0
     291.3     379.2     405.5     449.5
     291.3     379.2     405.5     449.5
     291.3     379.2     405.5     449.5
     291.3     379.2     405.5     449.5
     237.2     308.8     330.2     366.0
     237.2     308.8     330.2     366.0
     237.2     308.8     330.2     366.0
     237.2     308.8     330.2     366.0
       0.0       0.0       0.0       0.0
       0.0       0.0       0.0       0.0
       0.0       0.0       0.0       0.0
       0.0       0.0       0.0       0.0
```

Fig. 2. Savings estimates

```
SAVTOT IN $K:
EFF1 VARIES WITH K, EFF2 J, EFF3 I
         2658.7       2569.4       2542.6       2498.0
         2450.1       2297.8       2252.2       2176.1
         2424.6       2264.6       2216.7       2136.7
         2241.4       2026.3       1961.7       1854.1
         2367.4       2190.2       2137.1       2048.5
         2158.7       1918.7       1846.6       1726.6
         2133.2       1885.5       1811.1       1687.2
         1950.1       1647.1       1556.2       1404.7
         2313.3       2119.8       2061.8       1965.0
         2104.6       1848.2       1771.3       1643.1
         2079.1       1815.0       1735.8       1603.8
         1896.0       1576.6       1480.8       1321.2
         2076.1       1811.0       1731.5       1599.0
         1867.4       1539.5       1441.1       1277.1
         1841.9       1506.3       1405.6       1237.8
         1658.7       1267.9       1150.6        955.2

IMPL: 1467
 NO: 50

TOTAL 10 YEAR COSTS IN $K:      1967.0

NET 10 YEAR SAVINGS IN $K:
       24620.2      23727.3      23459.4      23012.9
       22533.6      21011.4      20554.7      19793.6
       22278.6      20679.5      20199.7      19400.2
       20447.1      18295.5      17650.1      16574.3
       21706.9      19935.4      19403.9      18518.1
       19620.4      17219.5      16499.3      15298.8
       19365.3      16887.6      16144.2      14905.4
       17533.8      14503.6      13594.6      12079.5
       21165.9      19231.2      18650.8      17683.4
       19079.3      16515.3      15746.1      14464.1
       18824.3      16183.4      15391.1      14070.6
       16992.7      13799.4      12841.4      11244.8
       18793.7      16143.5      15348.4      14023.4
       16707.1      13427.6      12443.8      10804.1
       16452.1      13095.7      12088.8      10410.6
       14620.5      10711.7       9539.1       7564.8
```

Fig. 2 (contd)

Appendix A

Graphs

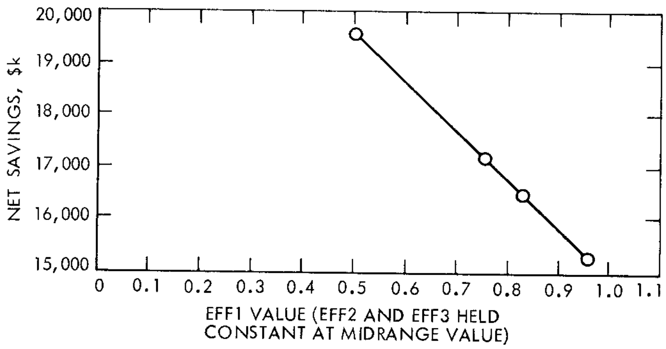

Fig. A-1. NETSAV vs EFF1

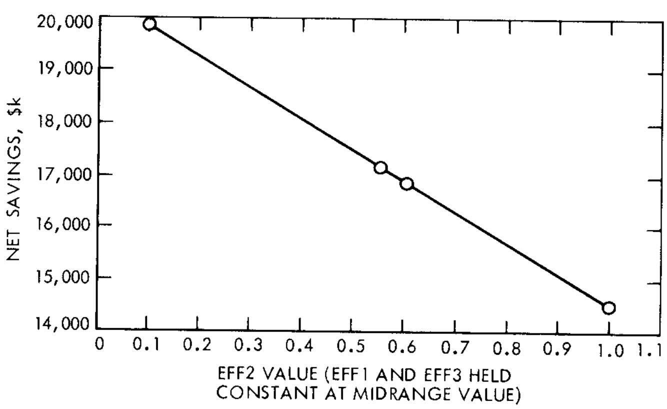

Fig. A-2. NETSAV vs EFF2

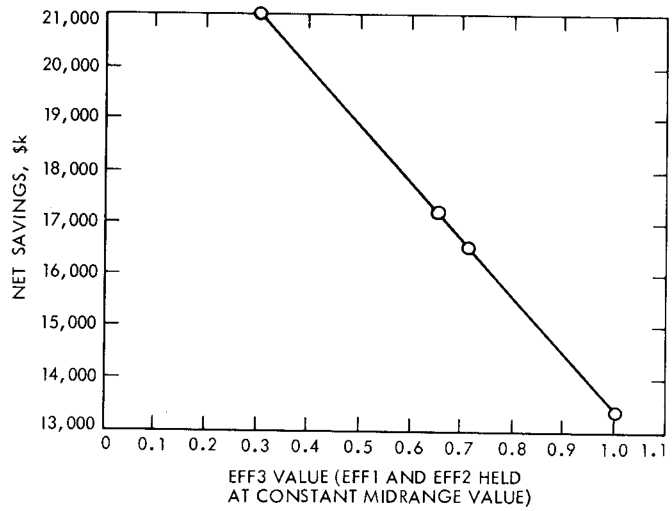

Fig. A-3. NETSAV vs EFF3

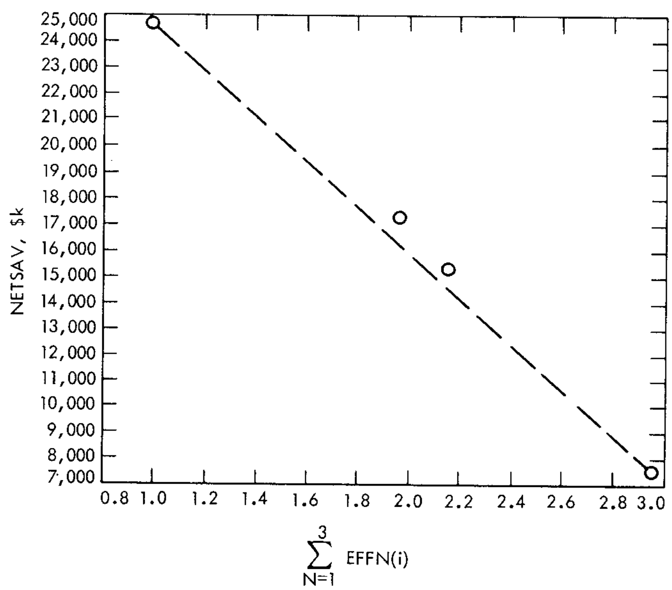

Fig. A-4. NETSAV vs $\sum_{N=1}^{3}$ EFFN (*i*), where *i* = 1 to 4. A graph of the four-dimensional NETSAV is impossible. This graph captures in two dimensions how NETSAV varies with all three parameters.

Appendix B

Program DBSAVE — Subprograms Initialize and Savings

The program DBSAVE is implemented in the DSN standard nonreal-time language MBASIC. Following top-down construction procedure, the program is divided into subprograms within which each statement is identified with a module number.

The first subprogram, Initialize, declares and prompts from the program user the values of all primary constants and variables. The second, subprogram Savings, calculates the range of possible ten-year net savings accompanying the unified computer data base system. Sensitivity, the last subprogram, calculates the degree to which the savings results would change with specified changes in the input constants and variables. The flowcharts follow.

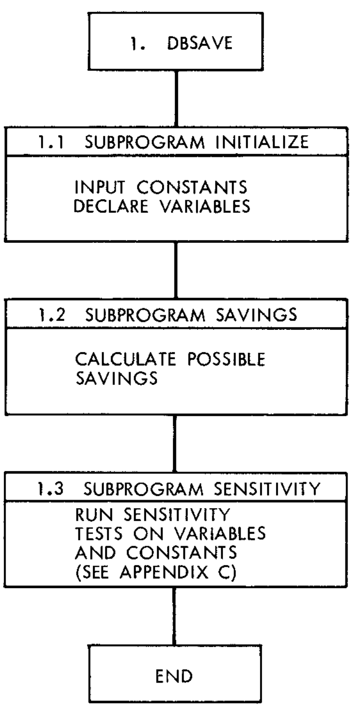

Fig. B-1. DBSAVE

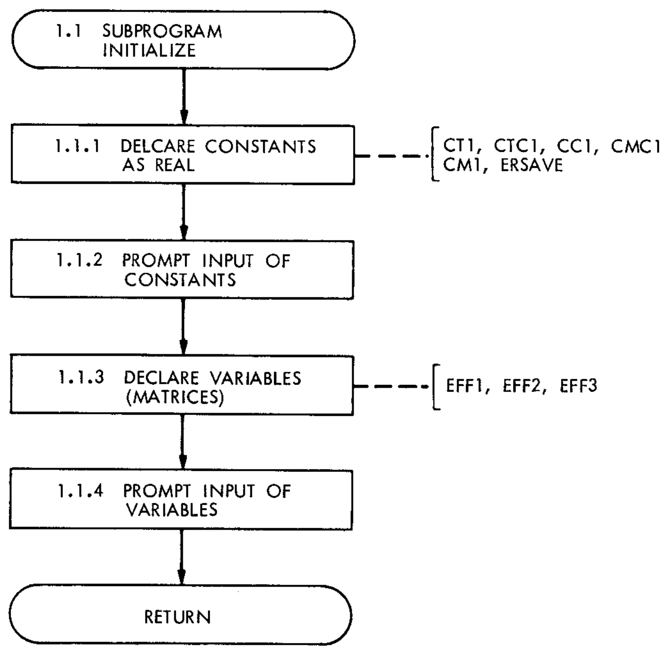

Fig. B-2. Subprogram Initialize

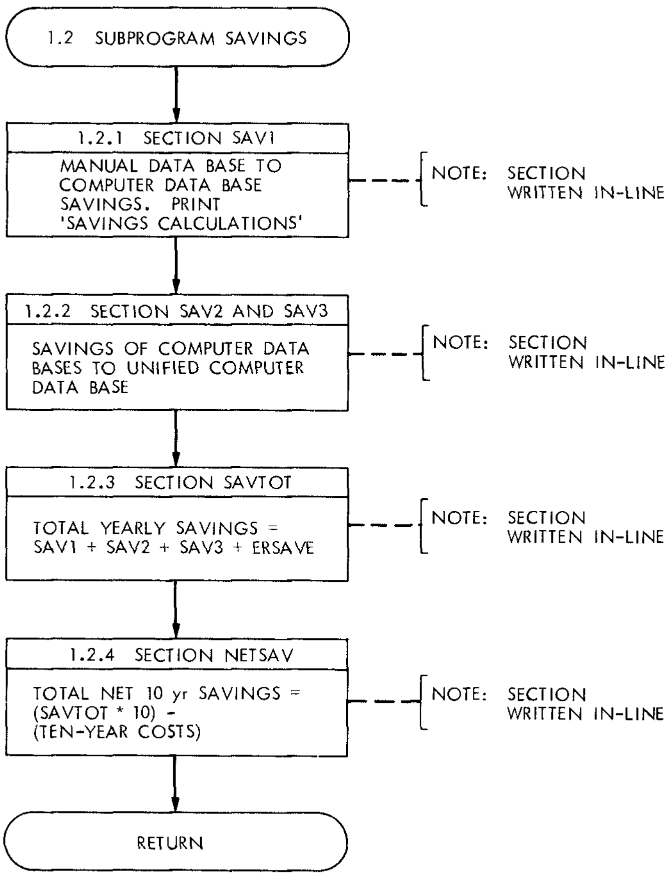

Fig. B-3. Subprogram Savings

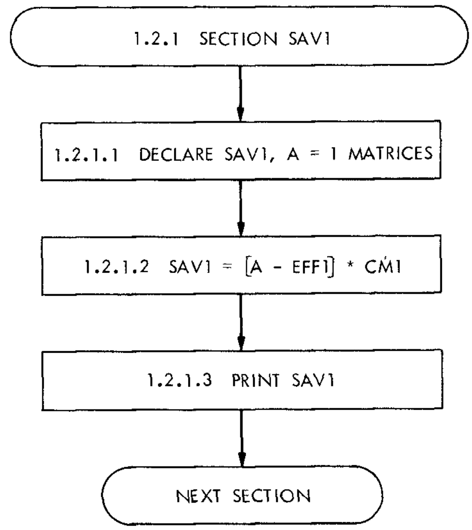

Fig. B-4. Section SAV1

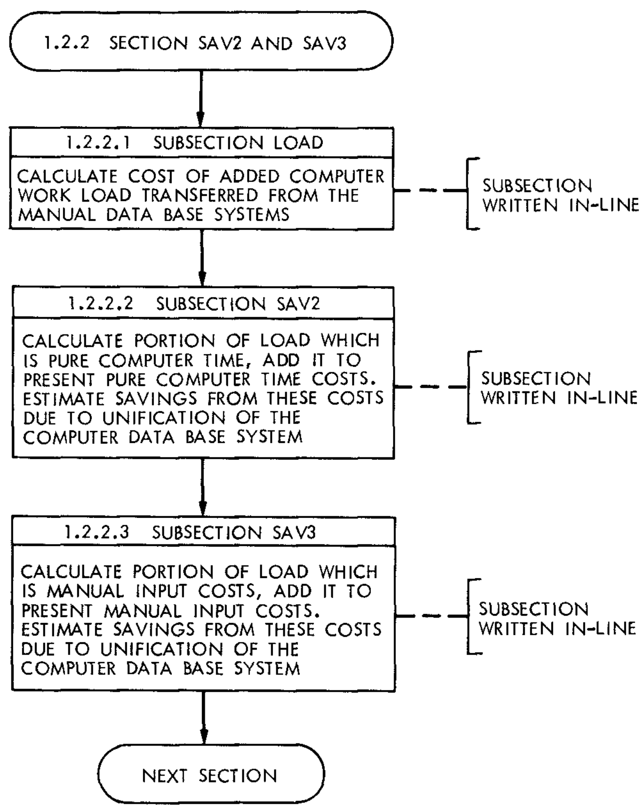

Fig. B-5. Section SAV2 and SAV3

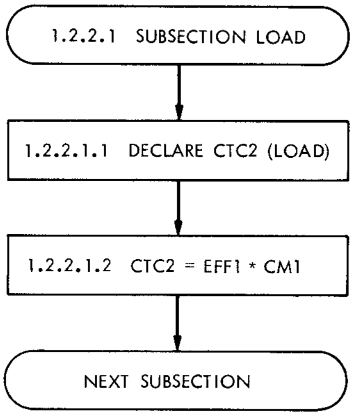

Fig. B-6. Subsection LOAD

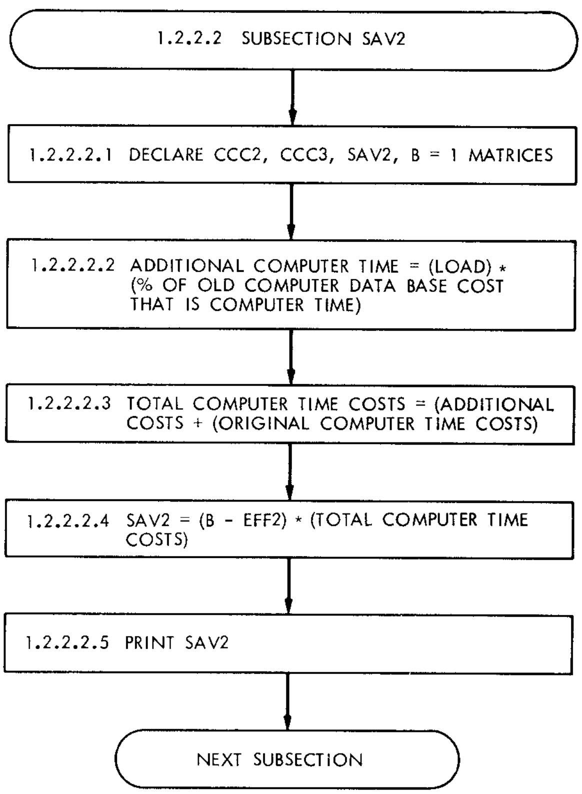

Fig. B-7. Subsection SAV2

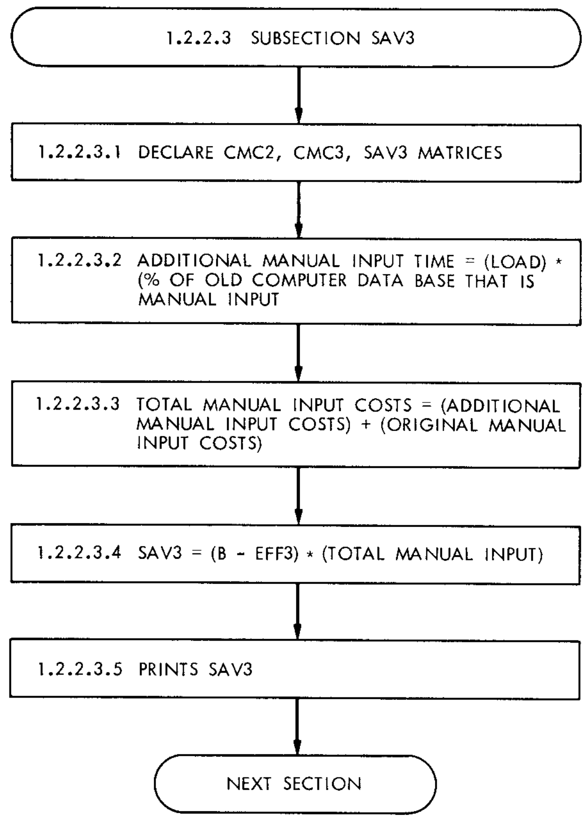

Fig. B-8. Subsection SAV3

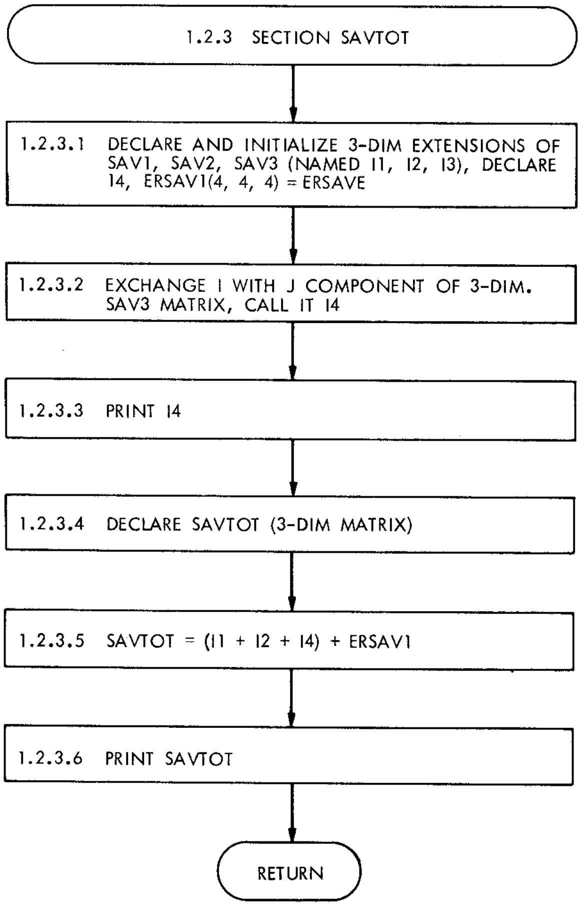

Fig. B-9. Section SAVTOT

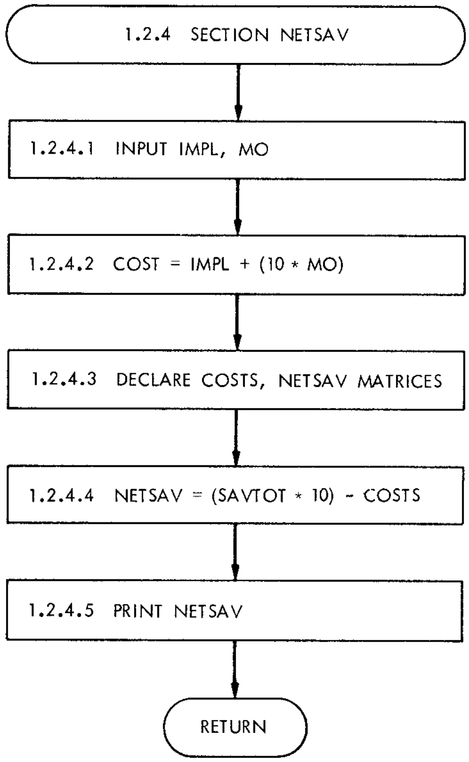

Fig. B-10. Section NETSAV

Appendix C

Program DBSAVE — Subprogram SENSITIVITY

The NETSAV value is clearly dependent upon the chosen value of the three efficiency ratios. The value of these ratios is not known. Yet, it would be useful to know, given three assumed values, the percent change in net savings due to a 10% change in the variables. This is the calculation of section Sensitivity: Variables.

The NETSAV matrix would also vary with different values of constants. This is doubly important since values of the constants depend on ballpark figures. The percent change in net savings due to a specified percent change in constants is the calculation of section Sensitivity: Constants.

Thus, subprogram Sensitivity is organized as shown in Fig. C-1.

I. Section Sensitivity: Variables

The goal is to calculate the percent change of NETSAV with respect to each of the variables, and then the percent change with respect to all three. This calculation is extremely easy if a trick is used in the input values of the variables. Specifically, for this study, the variable values were chosen such that:

$$\frac{\mathrm{EFF}N(3) - \mathrm{EFF}N(2)}{\mathrm{EFF}N(2)} = 10\% \qquad (\text{for } N = 1, 2, 3)$$

or, the third element in each efficiency vector is 10% greater than the value of the second element. The necessary NETSAV calculations are then included in the NETSAV matrix.

With this format for the vector values, the percent change of NETSAV with respect to EFF1, is:

```
DTLDE1 = (NETSAV(2, 2, 3) - NETSAV(2, 2, 2))/NETSAV(2, 2, 2)
```

Here, both EFF2 and EFF3 are held constant at their midrange values, EFF2(2) and EFF3(2), and EFF1 is varied 10%. Likewise, the other two percent changes are:

```
DTLDE2 = (NETSAV(2, 3, 2) - NETSAV(2, 2, 2))/NETSAV(2, 2, 2)

DTLDE3 = (NETSAV(3, 2, 2) - NETSAV(2, 2, 2))/NETSAV(2, 2, 2)
```

For the NETSAV percent change with respect to all three, the variables are changed 10% together, or

```
DTLDE = (NETSAV(3, 3, 3) - NETSAV(2, 2, 2))/NETSAV(2, 2, 2)
```

The flowchart for this section is given in Fig. C-2.

II. Section Sensitivity: Constants

Again, we want to calculate the percent change in net savings with respect to each constant. No easy trick will help in this section. Instead, the constant in question is increased a specified percent, and the net savings is then recalculated. For this study, the percent error factor, called ER, was chosen as 0.1, or 10%. The corresponding multiplier for the constants, ERR, is equal to 1 + ER, or 1.1.

For the percent change of NETSAV with respect to the constant CM1, the procedure is as follows. The NETSAV calculation is first stated in one equation:

```
NETSAV = ((1 - EFF1) * CM1

         + (1 - EFF2) * (CCC1 + CCC1/CTC1 * EFF1 * CM1)

         + (1 - EFF3) * (CMC1 + CMC1/CTC1 * EFF1 * CM1)

         + ERSAVE) * 10 - COST
```

Next, the constant, CM1, is multiplied by 1.1, or ERR; the variables are held at their midrange values; and the new NETSAV value, called DELSV1, is:

```
DELSV1 = ((1-EFF1(1,2))*CM1*ERR

         +(1-EFF2(2, 1))*(CCC1+CCC1/CTC1*EFF1(1, 2)*CM1*ERR)

         +(1-EFF3(2, 1))*(CMC1+CMC1/CTC1*EFF1(1, 2)*CM1*ERR)

         +ERSAVE)*10-COST
```

The percent change of NETSAV with respect to CM1, then, is:

```
DTDCM1 = (DELSV1 - NETSAV(2,2,2))/NETSAV(2,2,2)
```

The other percent changes – DTDCCC, DTDCTC, and DTDCMC – are calculated similarly. The flowchart and equations are given in Fig. C-3.

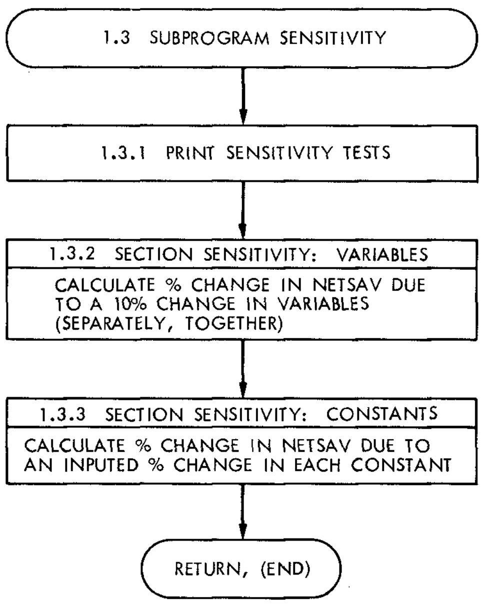

Fig. C-1. Subprogram Sensitivity

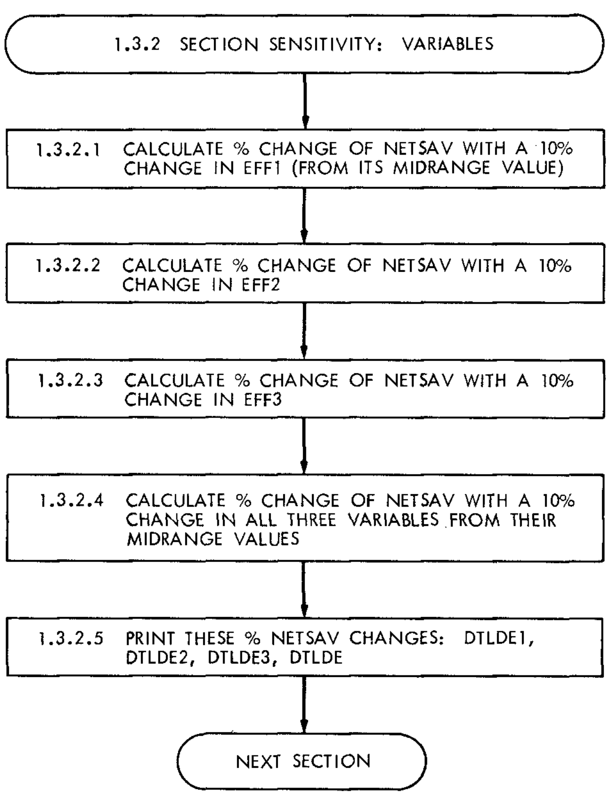

Fig. C-2. Section Sensitivity: Variables

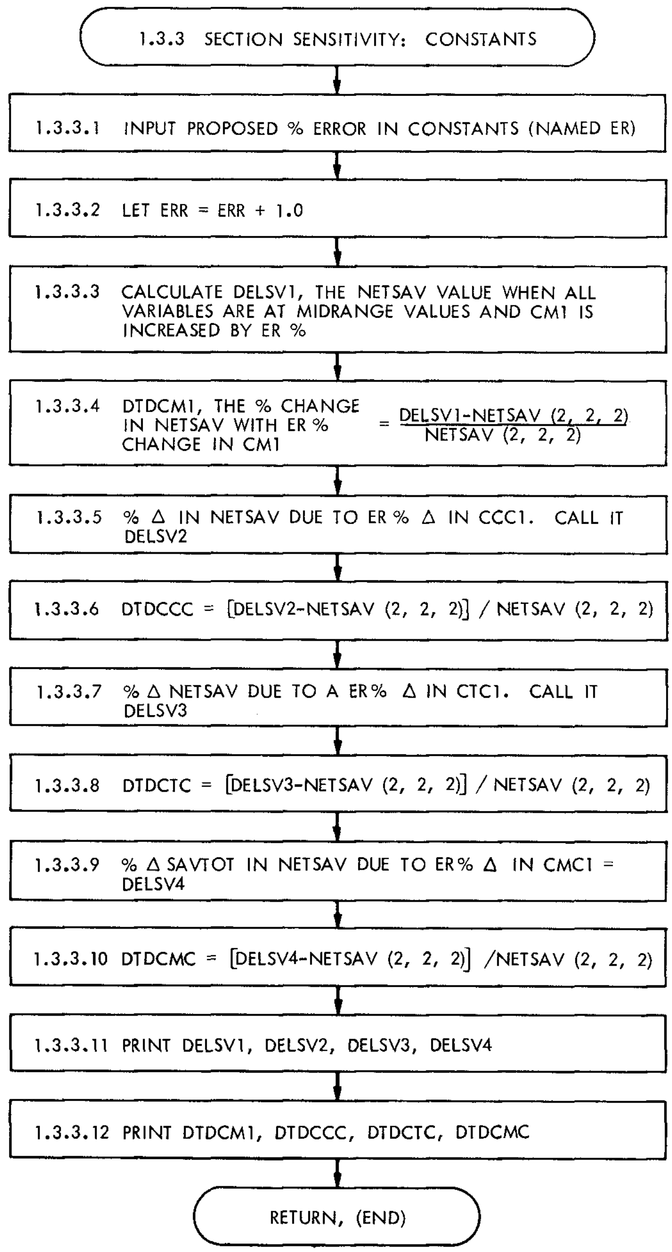

Fig. C-3. Section Sensitivity: Constants

Appendix D

Sensitivity Results

```
SENSITIVITY TESTS

DTLDE1=   -0.04
DTLDE2=   -0.02
DTLDE3=   -0.04
DTLDE=    -0.11

ERROR IN CONSTANTS : .1

DELSV1 IN $K=     18062.8
DELSV2 IN $K=     17491.1
DELSV3 IN $K=     16808.3
DELSV4 IN $K=     17598.7


DTDCM1=    0.05
DTDCCC=    0.02
DTDCTC=   -0.02
DTDCMC=    0.02

>EXIT
```


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